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MEASURING THYROID UPTAKE WITH HAND-HELD RADIATION MONITORS

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MEASURING THYROID UPTAKE WITH HAND-HELD RADIATION MONITORS

ABSTRACT

With the use of Iodine 123, 125 and 131 and some compounds of Technetium -99 m, a fraction of the isotopes can be trapped in the thyroid of the technicians.

We used the hand-held radiation contamination or survey meters of the nine (9) Nuclear medicine departments we visited to see if they were adequate for the evaluation of thyroid uptake of the users.

Measurements on a neck-phanton helped us to determine a minimum detectable activity for each isotope. We were then able to check if the measurements of investigation and action levels were possible.

None of the hand-held radiation monitors are completely satisfactory for the measure of thyroid uptake of the user. We discuss a class of equipment capable of measuring radiation emissions at the investigation level.

Measurement at the action level is possible with meters having scintillation or proportional probes but none of them permits the discrimination in energy required for a quantitative evaluation of the radioisotopes used.

RÉSUMÉ

Lors de l'utilisation d'iodes 123, 125 et 131 ainsi que certains composés marqués au technitium -99 m, une partie de ces radio-isotopes peut se retrouver dans la thyroïde des techniciens. Nous avons utilisé les moniteurs portatifs de radiation de neuf (9) départements de médicine nucléaire en vue de déterminer si ils étaient adéquats pour l'évaluation de la charge thyroïdienne chez les utilisateurs.

Les mesures effectuées à l'aide d'un mannequin-cou nous ont permis de déterminer une activités minimale détectable pour chacun des radio-isotopes et ensuite de juger si la mesure des niveaux d'investigation et d'action était possible.

Aucun des moniteurs portatifs vérifiés ne satisfait pleinement à la mesure du niveau d'investigation de la charge thyroïdienne chez les utilisateurs. Une classe d'appareil conforme est discutée.

Une mesure du niveau d'action est possible avec les moniteurs à sonde à scintillation ou à sonde proportionnelle, cependant aucun n'offre la discrimination en énergie permettant une évaluation quantitative en fonction des radio-isotopes manipulés.

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Introduction

When using some volatile radioisotopes or those where there is a significant amount of absorption through the skin, it is necessary to carry out bioassays. These bioassays make it possible to evaluate the internal radiation component on the basis of a model of standard man.

This study deals only with Iodine 123, 125, and 131, as well as with Technetium 99m. Table 1 shows the energies of the radioisotopes under consideration, as well as the available sources that allowed measurements at similar energies.

The possibility of using hand-held contamination measurement devices (CMD) and portable gamma detectors (GD) to measure the thyroid uptake of users in nine (9) Nuclear Medicine Departments throughout the country was evaluated. Some of their characteristics are shown in Table 2.

The devices studied were the CMD and GD monitors used by the various Departments visited. It was not in our mandate to check other available devices that were not portable.

Our task was to determine whether the use of the devices under consideration makes it possible to measure the thyroid uptake corresponding to various investigation levels of the radioisotopes I-123, I-125, I-131, and Tc-99m.

TABLE 1

Isotopes Used

Isotope Under Consideration	_ or X-ray Energies (MeV)
I-123	0.159 (83.4%)
I-125	0.027 (112%) 0.031 (25%) 0.035 (6.5%)
I-131	0.284 (6%) 0.364 (81%) 0.637 (7%)
Tc-99m	0.141 (89%)
Other Sources	
Co-57	0.122 (87%) 0.135 (11%)
Ba-133	0.302 (14%) 0.356 (69%)

Investigation Level

The investigation level used here corresponds to the definition given in the publication of the Working Group on Bioassay Guideline 3: Guidelines for Radioiodine Bioassay.[1] The investigation level is set at: 0.3 ALI/n, where ALI is the annual limit of intake, and n equals the number of individual measurements carried out during the year.

TABLE 2

Characteristics of the Centres Visited

Centre	Isotopes Used				Atomic Radiation Workers	Bioassays Carried Out
	I-123	I-125	I-131	Tc-99m		
A		X		X	YES	NO
B		X	X	X	NO	YES
C	X		X	X	YES	YES
D		X	X	X	NO	YES
E		X	X	X	NO	YES
F	(future)		X	X	YES	YES
G	X		X	X	YES	YES
H	X	X	X	X	YES	YES (partly)
J	X		X	X	YES	YES

The investigation level must be set on the basis of a single measurement and not on the basis of the uptake accumulated in one year.

The Federal-Provincial Working Group based its recommendations on Document 26 of the International Commission on Radiological Protection,[2] which allows a maximum annual thyroid dose of 500 mSv. In this case, a correction factor of 3/5 was used in order to be equivalent to the Canadian Atomic Energy Control Regulations, which set the maximum annual thyroid dose at 300 mSv.

The various investigation levels for the four (4) isotopes used are shown in Table 3. These levels were determined on the basis of results produced by the Working Group on Bioassay Guideline 3: Guidelines for Radioiodine Bioassay,[1] and Bioassay Guideline 5: Guidelines for Technetium 99m Bioassay.[3]

At present, there is a Canadian Regulation Guide[4] for Radioisotope licensees, which defines investigation and action levels for Atomic Radiation Workers and other people for Iodine 125 and Iodine 131. The investigation levels are 10 kBq of thyroid activity for Atomic Radiation Workers and 1 kBq for other people. The centres subject to this Guide should carry out their own comparisons against the values shown later in this document.

TABLE 3

Investigation Levels(1)

Isotope	Interval Between Measurements (days)	Investigation Level (Bq)
I-123	1	4,800
	2	2,800
	5	160
	7	18
I-125	1	180
	2	380
	5	900
	7	1,300
	14	2,200
	21	2,900
	28	3,500
	49	4,400
I-131	1	140
	2	260
	5	500
	7	590
	14	600
Tc-99m	1 (same day)	2.8E+4
	7 (50 times/yr)	1.4E+5
	35 (10 times/yr)	7.2E+5

(1) The investigation levels apply to Atomic Radiation Workers. For others, it is necessary to use 1/10 of the values shown.

MEASUREMENTS

In order to determine the sensitivity of the various CMD and GD devices under consideration on an equal basis, a neck-phantom from the Bureau of Radiation Protection and Medical Devices was used. The phantom is a tissue equivalent plastic model, which has a cavity at the level of the thyroid where it is possible to insert thyroid glands, and sources available in the various centres (Figure 1).

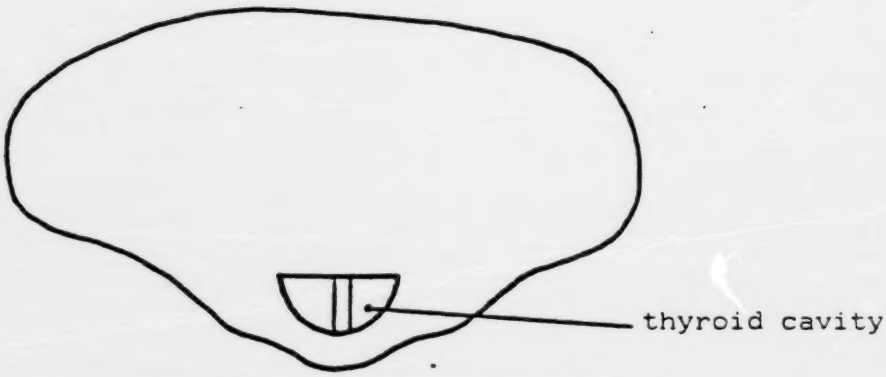
Except for the large surface proportional chamber monitors (100 and 200 cm^2), measurements were carried out at 5 cm from the surface of the neck,[5,6,7] in order to cover the two lobes of the thyroid and to minimize the effect of fluctuations in the effective depth of the gland. Thus, by placing the surface of the counter 5 cm in front of the neck, we were able to take into account the spatial distribution of the thyroid, as well as average absorption in the tissues.

The thyroids supplied with the phantom by the Bureau of Radiation Protection and Medical Devices used calibrated sources simulating Iodine 125 and Iodine 131. The activities distributed in the lobes were 10,800 Bq and 925 Bq for Iodine-131 and 7,330 Bq, 3,270 Bq and 530 Bq for Iodine-125.

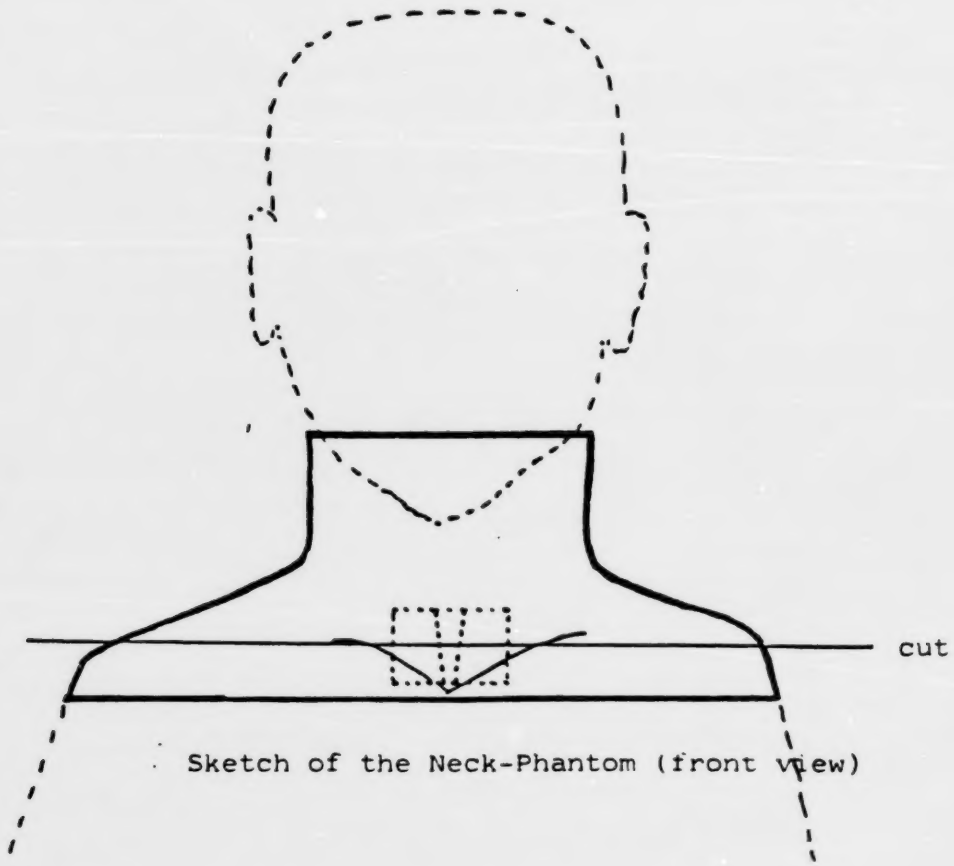
Point sources of Co-57 (80 Bq), as well as Ba-133 (2,740 Bq) were also available.

The sources in solution prepared in the various centres were provided in 3 to 5 cc syringes. Most of the Nuclear Medicine Departments supplied Tc-99m in solution. In addition, I-123 and I-131 in solution were also available.

Figure 1. Sketch of the Neck-Phantom



cut at the level of the thyroid



Sketch of the Neck-Phantom (front view)

The Departments had at least one point source of Co-57 available for use.

Point or solution sources were placed in the centre of the thyroid cavity of the phantom in order to carry out measurements with the CMD and GD devices.

The 100 and 200 cm^2 proportional chamber monitors were placed in contact with the neck, in order to cover the whole thyroid.

For the dosimeters, we observed the values displayed for about one (1) minute, and recorded the extreme values. The value of the minimum detectable activity (MDA) is the mathematical mean of the minimum and maximum observed values.

Ambient level measurements were taken in the morning, at noon, and at the end of the visit. Here again, an average based upon the minimum and maximum observed values was used.

MINIMUM DETECTABLE ACTIVITIES

In order to determine whether or not the hand-held devices could measure the thyroid activities corresponding to various investigation levels, measurements on the phantom as the basis for our evaluations of the minimum detectable activities (MDA) of each of the radioisotopes under consideration was used.

When available, we evaluated the MDA of an isotope on the basis of measurements of the same isotope. If the Department was unable to provide Tc-99m or I-123, the average of the measurements of other isotopes of similar energy, such as Co-57, was used.

In the case of the few devices that can integrate over a predetermined period of time, we used the following formula to obtain the minimum detectable activity[8]:

$$MDA = \frac{3\sqrt{\bar{B}}}{f}$$

where $\bar{B}$: is the average background dose rate
(examples: cpm, cts/second)

f: is the calibration factor; i.e., the dose rates of the source per unit of activity
(examples: cpm/100 Bq, cts/second/100 Bq).

However, most of the CMD and GD devices studies were dosimeters, in which case the use of the previous formula can hardly be justified; thus, we used the following formula:

$$MDA = \frac{2 \times \bar{B}}{f}$$

where $\bar{B}$: average of background dose rates

f: calibration factor; i.e., the dose rate per unit of activity.

POSSIBLE INTERFERENCES

For each of the Nuclear Medicine Departments visited, the factors that could affect the response of the various CMD and GD devices used was evaluated.

None of the Departments visited was subject to significant electromagnetic environment fields.

None of the Departments visited was close to any radiation-producing machines (X-ray machines).

In most of the Nuclear Medicine Departments visited, it is possible to carry out thyroid bioassays in a room sufficiently far from rooms housing cameras, waiting rooms where ambulatory sources (patients) may be present, or injection rooms. In this case, the background level varies very little as a function of the time of day so the minimum detectable activity values remain very stable.

When the only way to measure thyroid uptake was to carry out the work in a room containing a nuclear medicine camera, the task became very difficult, especially when there were patients in the vicinity. It would have been possible to obtain measurements in these rooms if the patients were not there, and the background level was measured and remained stable. MDA will change and should be recalculated each time. Different minimum detectable activities were recorded for the same monitor model. Average ambient levels, especially in the case of dosimeters, were not accurate, and varied from one centre to another; moreover, counting efficiencies also varied widely for the same hand-held monitor model.

EVALUATION QUESTIONNAIRES

In order to evaluate the Departments visited on the basis of the same criteria, certain evaluation forms were developed. Examples of these forms are shown in Appendix A. The first defines the uses and limits of the Departments; the second questionnaire describes the characteristics of the various CMD and GD devices evaluated and the third makes it possible to record the results obtained from measurements carried out in contact with the neck phantom, or 5 cm in front of the centre of the neck.

RESULTS FOR EACH NUCLEAR MEDICINE DEPARTMENT

On the basis of the measurements obtained with the phantom, thyroid glands with radioisotopes simulating Iodine-125 and Iodine-131, point sources of Ba-133, and Co-57, and sources available at each of the nine (9) departments visited, a table describing the performances of each available CMD and GD device was constructed.

Minimum detectable activity (MDA) was calculated for each of the isotopes, I-125, I-131, Tc-99m, and I-123, which made it possible to carry out comparisons against investigation levels. The investigation levels shown are those that apply for Atomic Radiation Workers. In the case of other workers, the investigation levels are 1/10 of those used.

Access to the two isotopes Tc-99m and I-123 was not always possible; however, in view of the fact that their energies are quite similar to that of Co-57 gamma radiation, we were able to assign them closely representative average values.

When the MDA was higher than the investigation level, the device was judged to be unsatisfactory. However, when the MDA was equal to or lower than an investigation level, the device was judged to be satisfactory for measuring that investigation level for the radioisotope under consideration. Thus, Appendix B shows the results for a specific device and probe as follows: "y" = yes, it is satisfactory; or "N" = no, it is not satisfactory; a "-" indicates that no evaluation was required or possible with the available sources.

The following is a summary of the investigation levels that we were able to measure satisfactorily for all the CMD and GD devices studied in each of the centres visited.

DEPARTMENT A, monitor acceptable at frequencies shown.

- Geiger counter (mica window) (Table 1), and sideways to the steel shield (Table 2)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Others Workers
  Tc-99m at 35 days

- Ionization chamber dosimeter, front measurements without protective shield) (Table A-3), and front measurements with shield (Table A-4).

  ° Atomic Radiation Workers
  Tc-99m at 35 days

  ° Other Workers
  None

In this case, it is important to mention that the MPA was based on the activity that makes it possible to obtain a digital reading of 0.1 mR/hr; that is, the smallest value displayed. None of the devices able to meet their needs completely.

DEPARTMENT B, monitor acceptable at frequencies shown.

- 100 cm^2 proportional probe monitor, measurements in contact with the neck. (Table B-1)

  ° Atomic Radiation Workers
  I-125 at 14, 21, 28, and 49 days
  Tc-99m, all

  ° Other Workers
  Tc-99m at 7 and 35 days

- Scintillation probe monitor, 1" Ø x 1 mm (Table B-2)

  ° Atomic Radiation Workers
  I-125 from 5 to 49 days
  I-131 from 5 to 14 days
  Tc-99m all
  I-123, day of use

  ° Other Workers
  Tc-99m at 7 and 35 days

- Geiger counter (mica window) (Table B-3), and sideways (Table B-4)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  None

- Geiger counter, sideways to the probe (Table B-5)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  Tc-99m at 35 days

- Scintillation probe monitor, 1" Ø x 1 mm crystal (Table B-6)

  ° Atomic Radiation Workers
  I-125 from 14 to 49 days
  Tc-99m all

  ° Other Workers
  Tc-99m at 7 and 35 days

- Monitor with pancake Geiger counter (Table B-7)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  Tc-99m at 35 days

- Geiger counter (Table B-8)

  ° Atomic Radiation Workers
  None

  ° Other Workers
  None

None of these devices able to meet all their requirements for Atomic Radiation Workers; however, the Amersham Ibrinator is <u>almost</u> satisfactory for the workers.

DEPARTMENT C, monitor acceptable at frequencies shown.

- Geiger counter (mica window) (Table C-1)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  Tc-99m at 35 days

- Scintillation probe monitor, 1" Ø x 1" (Table C-2)

  ° Atomic Radiation Workers
  Tc-99m: all

  ° Other Workers
  Tc-99m at 7 and 35 days

- Geiger probe counter (mica window) (Table C-3)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  None

None of these devices was able to meet all their requirements

DEPARTMENT D, monitor acceptable at frequencies shown.

- 100 cm^2 proportional probe monitor (Table D-1)
  Probe in contact with neck.

Two MDA values for Iodine-125 and Tc-99m were calculated. The lowest of the two numbers was obtained from measurements of background level in a laboratory used to carry out bioassays for Iodine-125. The higher number was obtained from measurements carried out in a camera room in the same Nuclear Medicine Department that is used to carry out bioassays for Iodine-131.

° Atomic Radiation Workers, camera room
Tc-99m: all

° Other Workers
Tc-99m at 35 days

° Atomic Radiation Workers, laboratory
I-125 at 5, 7, 14, 21, 28, and 49 days
Tc-99m: all

° Other Workers
Tc-99m: all

- Geiger probe counter (mica window) (Table D-2), and sideways to the shield (Table D-3)

° Atomic Radiation Workers
Tc-99m at 35 days

° Other Workers
None

- Thick-walled Geiger probe counter (Table D-4).
None

None of these devices was able to meet all their needs.

DEPARTMENT E, monitor acceptable at frequencies shown.

- Thin window Geiger counter (Table E-1)

  ° Atomic Radiation Workers
  Tc-99m: all

  ° Other Workers
  Tc-99m at 35 days

- Geiger counter (mica window) (Table E-2), and sideways (Table E-3).

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  Tc-99m at 35 days

None of these devices was able to meet their needs.

DEPARTMENT F, monitor acceptable at frequencies shown.

- Geiger probe counter (mica window) (Table F-1)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  Tc-99m at 35 days

- Geiger probe counter, sideways to the 30 mg cm^2 steel window (Table F-2)

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Others Workers
  Tc-99m at 35 days

None of these devices was able to meet their needs.

DEPARTMENT G, monitor acceptable at frequencies shown.

- Geiger probe counter, sideways to the 30 mg cm^2 window (Table G-1).

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Others Workers
  Tc-99m at 35 days

- Ionization chamber monitor (thin window) (Table G-2).

  ° Atomic Radiation Workers
  None

  ° Other Workers
  None

None of these devices was able to meet their needs.

DEPARTMENT H, monitor acceptable at frequencies shown.

- Geiger probe counter (mica window) (Table H-1).

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  Tc-99m at 35 days

- Geiger probe counter, (1" Ø mica window) (Table H-2).

  ° Atomic Radiation Workers
  Tc-99m at 7 and 35 days

  ° Other Workers
  None

None of these devices was able to meet their needs.

DEPARTMENT J, monitor acceptable at frequencies shown.

- Pancake Geiger probe counter (mica window) (Table J-1) (only I-125 and I-131 were evaluated).

  ° Atomic Radiation Workers
  None

  ° Other Workers
  None

- Scintillation probe monitor, 2" Ø x 2 mm (Table J-2).

  ° Atomic Radiation Workers

    I-125 at 14, 21, 28, and 49 days

    Tc-99m, all

    I-123, the day of use

  ° Other Workers

    Tc-99m at 7 and 35 days

- Integration monitor with a 1" x 1" crystal for a period of 1 minute (Table J-3).

  ° Atomic Radiation Workers

    I-125, all, except interval of one day

    I-131 at 5, 7, and 14 days

    Tc-99m, all

    I-123 at 1 or 2 days from use

  ° Other Workers

    I-125 at 21, 28, and 49 days

    Tc-99m, all

    I-123 after 1 or 2 days from use

- Integration monitor with compensated Geiger probe for a period of 1 minute (Table J-4).

  ° Atomic Radiation Workers

    Tc-99m at 7 and 35 days

  ° Other workers

    Tc-99m at 35 days

- 200 cm^2 proportional probe monitor (Table J-5).

  ° Atomic Radiation Workers

  I-125 at 14, 21, 28, and 49 days

  Tc-99m: all

  I-123, the day of manipulation only

  ° Others Workers

  Tc-99m at 7 and 35 days

The only device that was able to meet <u>almost</u> all needs was the Eberline ESP-1 Monitor with a 1" x 1" scintillation probe and integration of counts over periods of 1 minute. The crystal was shielded by 1/8 of an inch of lead over a length of 2-3/4 inches.

CONCLUSIONS, INVESTIGATION LEVELS

None of the CMD and GD devices studied was able to meet all requirements in respect of the measurement of investigation levels for all the time intervals required, and for all the radioisotopes used in the Nuclear Medicine Departments visited. None of the devices was able to detect thyroid activities equivalent to all investigation levels for Atomic Radiation workers. Thus, given that the investigation levels for non-Atomic Radiation workers are lower by a factor of 10, we were very far from the measurement levels required for this group.

Moreover, none of the CMD and GD devices studies made it possible to obtain energy discriminations, which made it impossible to determine internal radiation, especially in view of the fact that the investigation levels for the various isotopes, as well as counting efficiencies, were different. As an example, let us consider the Amersham Ibrinator for a measurement of 100 cts/second at 5 cm from the neck. This can be interpreted as follows:

I-125:	Bq in the thyroid
or, I-131:	n the thyroid
or, Tc-99m:	780,000 Bq in the thyroid
or even, I-123:	590,000 Bq in the thyroid

In spite of the fact that none of the devices studied was satisfactory, the best were those that made it possible to integrate on the basis of periods of time of at least one minute or more, and that used a scintillation probe [NaI(Tl) crystal] detector.

RECOMMENDATIONS, INSTRUMENTATION

The devices used to measure thyroid activity at investigation levels both for Atomic Radiation workers and other workers should have the following characteristics:

- Monitor with possibility of count integration for at least 10 minutes
- At least a single channel monitor with the capacity of counting within an energy window. The device rejects counts at energies higher or lower than those defined by the window.
- Scintillation probes.
  I-125, a NaI(Tl) probe measuring at least one (1) inch in diameter by 1 to 2 mm thick.
  Others, a NaI(Tl) probe measuring at least one (1) inch in diameter by 1 inch thick.

Integration times are adjusted as a function of the minimum activity to be detected and the desired precision.

AVAILABLE SINGLE CHANNEL MONITORS

- LUDLUM, 2200 Model
  AC and batteries

- BICRON, Labtech Model
  AC and batteries

- EBERLINE, ESP or SRM models with a pulse analyser option (PHA)
  AC or batteries

- Nuclear Enterprises, PSR-8 Model
  AC and batteries

- Technical Associates , FS-8C Model
  AC and batteries

- Other companies offer equivalent devices.

All companies offer scintillation probes. It is necessary to ensure that the probes obtained have the above-mentioned characteristics.

ACTION LEVELS

The action level is that quantity of radioisotope in the body which on the basis of a single measurement would indicate that the thyroid dose could exceed the annual dose limit of 300 mSv.

Here again, thyroid count action levels were based on the publications of the Working Group on Bioassay Guidelines 3[1] and 5[3]. A factor of 3/5 was applied to these criteria for an annual thyroid uptake limit of 300 mSv. The corrected action levels are shown in Table 4 as a function of the sampling interval. These levels apply for Atomic Radiation workers; for other workers we must use 1/10 of these values.

The results obtained with proportional probe monitors with surfaces of 100 and 200 cm^2 are shown in Table 5. The three (3) devices were satisfactory for measuring thyroid activity equal to the action level, both for Atomic Radiation workers and for other workers. In the tables used to evaluate the monitors at the action levels, the legend "not evaluated" indicates that we were unable to determine minimum detectable activity, and consequently could not determine whether or not the device can be used to obtain measurement at the desired action level.

For scintillation probe [NaI(Tl)] monitors, the results are shown in Table 6. Four (4) of the five (5) monitors were found to be acceptable for all radioisotopes. The fifth consists of a rate meter and a 1" Ø x 1" NaI(Tl) probe, and could not be evaluated for Iodine-125; it could not detect the presence of our most active thyroid at this energy level (7,300 Bq). Moreover, this device could not be used to measure the action level in other workers at an interval of 14 days.

TABLE 4 - ACTION LEVELS

Isotope	Interval between measurements (days)	Action level (Bq)
I-123	1	5.8E+6
	2	1.7E+6
	5	3.9E+4
	7	3.1E+3
I-125	1	2.2E+5
	2	2.3E+5
	5	2.2E+5
	7	2.2E+5
	14	1.9E+5
	21	1.7E+5
	28	1.5E+5
	49	1.1E+5
I-131	1	1.6E+5
	2	1.6E+5
	5	1.3E+5
	7	1.0E+5
	14	5.5E+4
Tc-99M	Calculated 6 hours after manipulation	2.3E+7

TABLE 5

Performance of Proportional Counter
at Action Levels

Isotope / Interval (days)	Action Level (Bq)	Atomic Radiation Workers			Other Workers		
		S	US	NE	S	US	NE
I-125							
1	2.2E+5	3	0	0	3	0	0
2	2.3E+5	3	0	0	3	0	0
5	2.2E+5	3	0	0	3	0	0
7	2.2E+5	3	0	0	3	0	0
14	1.9E+5	3	0	0	3	0	0
21	1.7E+5	3	0	0	3	0	0
28	1.5E+5	3	0	0	3	0	0
49	1.1E+5	3	0	0	3	0	0
I-131							
1	1.6E+5	3	0	0	3	0	0
2	1.6E+5	3	0	0	3	0	0
5	1.3E+5	3	0	0	3	0	0
7	1.0E+5	3	0	0	3	0	0
14	5.5E+4	3	0	0	3	0	0
Tc-99m							
Same Day	2.3E+7	3	0	0	3	0	0
I-123							
1	5.8E+6	3	0	0	3	0	0
2	1.7E+6	3	0	0	3	0	0
5	3.9E+4	3	0	0	0	3	0
7	3.1E+3	0	3	0	0	3	0

S = satisfactory
US = unsatisfactory
NE = not evaluated

TABLE 6

Performance of Scintillation [NaI(Tl)] Probes at Action Levels

Isotope / Interval (days)	Action Level (Bq)	Atomic Radiation Workers			Other Workers		
		S	US	NE	S	US	NE
I-125							
1	2.2E+5	4	0	1	4	0	1
2	2.3E+5	4	0	1	4	0	1
5	2.2E+5	4	0	1	4	0	1
7	2.2E+5	4	0	1	4	0	1
14	1.9E+5	4	0	1	4	0	1
21	1.7E+5	4	0	1	4	0	1
28	1.5E+5	4	0	1	4	0	1
49	1.1E+5	4	0	1	4	0	1
I-131							
1	1.6E+5	5	0	0	5	0	0
2	1.6E+5	5	0	0	5	0	0
5	1.3E+5	5	0	0	5	0	0
7	1.0E+5	5	0	0	5	0	0
14	5.5E+4	5	0	0	4	1	0
Tc-99m							
Same Day	2.3E+7	5	0	0	5	0	0
I-123							
1	5.8E+6	5	0	0	5	0	0
2	1.7E+6	5	0	0	5	0	0
5	3.9E+4	5	0	0	3	2	0
7	3.1E+3	2	3	0	1	4	0

S = satisfactory
US = unsatisfactory
NE = not evaluated

Table 7 shows the results of Geiger and ionization chamber counters. These are the most commonly used monitors; Geiger counters are good detectors and the chambers represent excellent dosimeters; however, they cannot be recommended for thyroid bioassays.

Over 40% of these devices could not detect the presence of our source of Iodine-125 (7,300 Bq) in the thyroid and more than 20% were unable to detect the presence of 10,800 Bq of Iodine-131. Most were able to show the presence of Tc-99m at action levels; however, determination of the radioisotopes used was not possible since these monitors do not allow identification of the measured gamma energy.

Thyroid activities that correspond to the action levels are detectable with good hand-held scintillation probe or large surface proportional chamber monitors. However, these devices do not make it possible to identify which of the radioisotopes is present in the thyroid of users in Nuclear Medicine, where several isotopes are routinely used.

TABLE 7

Performance of Geiger Counters
and Ionization Chamber Monitors

Isotope / Interval (days)	Action Level (Bq)	Atomic Radiation Workers			Other Workers		
		S	US	NE	S	US	NE
I-125							
1	2.2E+5	14	0	11	14	0	11
2	2.3E+5	14	0	11	14	0	11
5	2.2E+5	14	0	11	14	0	11
7	2.2E+5	14	0	11	14	0	11
14	1.9E+5	14	0	11	14	0	11
21	1.7E+5	14	0	11	14	0	11
28	1.5E+5	14	0	11	14	0	11
49	1.1E+5	14	0	11	11	3	11
I-131							
1	1.6E+5	19	0	6	16	3	6
2	1.6E+5	19	0	6	16	3	6
5	1.3E+5	19	0	6	15	4	6
7	1.0E+5	18	1	6	12	7	6
14	5.5E+4	18	1	6	8	11	6
Tc-99m							
Same Day	2.3E+7	24	0	1	24	0	1
I-123							
1	5.8E+6	24	0	1	21	3	1
2	1.7E+6	23	1	1	17	7	1
5	3.9E+4	6	18	1	0	24	1
7	3.1E+3	0	24	1	0	24	1

S = satisfactory
US = unsatisfactory
NE = not evaluated

CONCLUSIONS

As the result of visits to nine (9) Nuclear Medicine Departments in Canada, during which the possibility of measurement at investigation and action level of Iodine-123, Iodine-125, Iodine-131, and Tc-99m was evaluated, the following conclusions were reached:

- measurement at action levels

  : acceptable with scintillation counters and large surface proportional counters;

  : unacceptable with most Geiger counters or ionization chamber monitors;

- measurement at investigation levels

  : acceptable with monitors that allow integration over time with appropriate scintillation probes for Iodine-125 and for the other isotopes;

  : unacceptable for all other types of monitors.

- none of the CMD (contamination measurement devices) and GD (gamma detection) monitors studied was energy-specific; thus, it was impossible to link results of measurements with radioisotopes used, and consequently, it was impossible to calculate internal exposure, or to determine whether the investigation or action levels were effectively reached or exceeded.

- thus, more sophisticated monitors are required for bioassays of the thyroids of users of Iodine-123, -125, and -131, and of Technetium-99m.

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APPENDIX A

EVALUATION QUESTIONNAIRES

Radioprotection Inc.

340 des Bouleaux, Ste-Julie, Qué. J0L 2S0

(514) 649 5213

MESURE DE LA CHARGE THYROIDIENNE EN UTILISANT DES MONITEURS PORTATIFS DE RADIATION

INSTITUTION : B

Personne rencontrée: ~

Date: ~

Le personnel est travailleur sous rayonnement: oui .... non. ✓

Radioisotopes utilisés:

	OUI	NON
Iode-123		✓
Iode-125	✓	
Iode-131	✓	
Tc-99m	✓	

Local où sont effectuées nos mesures

-possibilité de champs électro-magnétiqes: Oui ... Non. ✓
remarques:

-proximité d'appareils producteurs de radiation ou de sources radioactives: Oui ... Non. ✓
remarques:

-autres interférences: N/A

-même local que bio-essais réguliers: Oui ... Non ✓ N/A ...
remarques: même environnement que bio-essais réguliers, mais pas la même salle car patients dans salle d'examen

Radioprotection Inc. | (514) 649-5213
340 des Bouleaux, Ste-Julie, Qué. J0L 2S0

B

APPAREIL UTILISE

Fabricant: Nuclear Chicago

Modèle: 2650

No série: B.4577.M

Sonde; Type: 2.6.6.1

Caractéristiques: Geiger, fenêtre mince en bout de tube, 2 mg cm⁻²

Constante de temps utilisée: "Long"

Réponse en énergie (selon manuel): N/A

Sensibilité (selon manuel): N/A

MESURES DU NIVEAU D'AMBIANCE

Matin (10 h 14): 0.006 - 0.030 mR/h

Mi-journée (13 h 33): 0.009 - 0.032 mR/h

Fin journée (h): —

Autres:

B

7 de 15

MESURES

APPAREIL : Searle Nuclear Chicago

MODELE: 2650 SERIE:

SONDE: Geiger

MODE D'UTILISATION: mesure 2 mg/cm²
en bout de tuyau

I-125 198.2 nanoCi (7 330 Bq) (simulee)
contact: 0.016 - 0.050 mR/h Ech.: 0.1 mR/h max
'a 5 cm: 0.008 - 0.030 " Ech.:

88.5 nanoCi (3 270 Bq) (simulee)
contact: 0.008 - 0.028 Ech.: 0.1 mR/h max
'a 5 cm: 0.009 - 0.031 Ech.:

14.4 nanoCi (530 Bq) (simulee)
contact: 0.008 - 0.028 Ech.: 0.1 mR/h max
'a 5 cm: 0.009 - 0.027 Ech.: 0.1 mR/h max

I-125 (Bq)
contact: Ech.:
'a 5 cm: Ech.:

I-131 292 nanoCi (10 800 Bq) (simulee)
contact: 0.096 - 0.10 Ech.: 0.1 mR/h max
'a 5 cm: 0.024 - 0.044 Ech.: 0.1 mR/h max

25 nanoCi (925 Bq) (simulee)
contact: 0.006 - 0.036 Ech.: 0.1
'a 5 cm: 0.009 - 0.034 Ech.: 0.1

Ba-133 74 nanoCi (2 740 Bq)
contact: 0.028 - 0.038 Ech.: 0.1 mR/h
'a 5 cm: 0.014 - 0.028 Ech.: "

Tc-99m et I-123
Co-57 2.2 nanoCi (80 Bq)
contact: 0.016 - 0.020 Ech.: 0.1 mR/h max.
'a 5 cm: 0.006 - 0.020 Ech.: 0.1 "

Source: Co-57 5.2 µCi (192.4 kBq)
contact: 0.55 - 0.62 Ech.: 1 mR/h max.
'a 5 cm: 0.12 - 0.18 Ech.: 0.3 "

Source: Tc-99m , 7.4 µCi (273.8 kBq)
contact: 0.36 - 0.44 mR/h Ech.: 1
'a 5 cm: 0.12 - 0.15 " Ech.: 0.3

Source: Tc-99m 169 µCi (6250 kBq)
contact: 9 - 12 mR/h Ech.: 30
'a 5 cm: 2.2 - 2.7 " Ech.: 10

Source:
contact: Ech.:
'a 5 cm: Ech.:

Source:
contact: Ech.:
'a 5 cm: Ech.:

APPENDIX B

PERFORMANCE OF THE DEVICES

INVESTIGATION LEVELS

TABLE A-1

PERFORMANCE OF THE DEVICES

Device: Nuclear Chicago 2652 — Probe: Geiger
Utilization: end of the tube, mica 2mg cm^{-2} — Centre: A

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		7 500		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		5 400		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		4.0E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(30 000)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		20 000	-	-
Ba-133		-	-	-

(1) N = NO
Y = YES
- = not applicable

(2) Value shown is an average of measurements of other similar energy sources.

TABLE A-2

PERFORMANCE OF THE DEVICES

Device: Nuclear Chicago 2652 — Probe: Geiger
Utilization: lateral, stainless steel — Centre: A

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 300		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		9 700		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		3.6E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		32 000		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		28 000	-	-
Ba-133		-	-	-

(1) N = NO
Y = YES
- = not applicable

(2) Value shown is an average of measurements of other similar energy sources.

TABLE A-3

PERFORMANCE OF THE DEVICES

Device: Keithley 36150 Probe: Ionization chamber
Utilization: in front without cap Centre: A

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		> 11 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		5E+5		
1	2.8E+4		N	N
7	1.4E+5		N	N
35	7.2E+5		Y	N
I-123		(4E+5)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		3.E+5	-	-
Ba-133		-	-	-

(1) N = NO
Y = YES
- = not applicable

(2) Value shown is an average of measurements of other similar energy sources.

TABLE A-4

PERFORMANCE OF THE DEVICES

Device: Keithley 36150 — Probe: Ionization chamber
Utilization: in front with cap on — Centre: A

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory Atomic Radiation Workers (1)	Satisfactory Others Workers (1)
I-125		> 7 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		> 10 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		5.9E+5		
1	2.8E+4		N	N
7	1.4E+5		N	N
35	7.2E+5		Y	N
I-123		(4.7E+5)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		3.4E+5	-	-
Ba-133		-	-	-

(1) N = NO
Y = YES
- = not applicable

(2) Value shown is an average of measurements of other similar energy sources.

TABLE B-1

PERFORMANCE OF THE DEVICES

Device: Berthold LB 2120B — Probe: 100 cm^2 proportional counter

Utilization: in front (5mg cm^2 titanium) — Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity (3) (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		1 500		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		Y	N
21	2 900		Y	N
28	3 500		Y	N
49	4 400		Y	N
I-131		920		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		6.8E+3		
1	2.8E+4		Y	N
7	1.4E+5		Y	Y
35	7.2E+5		Y	Y
I-123		(5 600)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		4 500	-	-
Ba-133		910	-	-

(1) N = NO / Y = YES / - = not applicable

(2) Value shown is an average of measurements of other similar energy sources.

(3) MDA calculated on the basis of values measured with the neck in contact with the proportional chamber.

TABLE B-2

PERFORMANCE OF THE DEVICES

Device: Amersham IBRINATOR — Probe: Scintillation
Utilization: in front a 1" Ø x 1 mm crystal — Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity $\frac{(3\ B)}{f}$ (3) (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		700		
1	180		N	N
2	380		N	N
5	900		Y	N
7	1 300		Y	N
14	2 200		Y	N
21	2 900		Y	N
28	3 500		Y	N
49	4 400		Y	N
I-131		310		
1	140		N	N
2	260		N	N
5	500		Y	N
7	590		Y	N
14	600		Y	N
Tc-99m		4.3E+3		
1	2.8E+4		Y	N
7	1.4E+5		Y	Y
35	7.2E+5		Y	Y
I-123		(3.5E+3)(2)		
1	4 800		Y	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		2.6E+3	-	-
Ba-133		320	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.
(3) Integration: 50 seconds. Measures taken at 5 cm from the phantom.

TABLE B-3

PERFORMANCE OF THE DEVICES

Device: Searle 2650 Probe: Geiger
Utilization: end of tube, 2mg cm^{-2} mica Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		≥ 14 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		12 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		8.7E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	N
I-123		(68 000)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		49 000	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE B-4

PERFORMANCE OF THE DEVICES

Device: Searle 2650 Probe: Geiger
Utilization: lateral, stainless steel Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		16 500		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		128 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		9E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	N
I-123		(59 000)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		59 000	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE B-5

PERFORMANCE OF THE DEVICES

Device: Victoreen 498 — Probe: Geiger
Utilization: lateral, stainless steel — Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 400		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		≥ 11 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		4E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(40 000)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		4E+4	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE B-6

PERFORMANCE OF THE DEVICES

Device: Ludlum, Model 3 — Probe: Scintillation
Utilization: in front, 1" Ø x 1 mm crystal — Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		1 700		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		Y	N
21	2 900		Y	N
28	3 500		Y	N
49	4 400		Y	N
I-131		650		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		6.9E+3		
1	2.8E+4		Y	N
7	1.4E+5		Y	Y
35	7.2E+5		Y	Y
I-123		(5 700)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		4.5E+3		-
Ba-133		1 200		-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE B-7

PERFORMANCE OF THE DEVICES

Device: Ludlum, Model 3 — Probe: Geiger, "pancake"
Utilization: in front, 2 mg cm^{-2} mica — Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		11 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		7 900		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		6E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(5.4E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		4.8E+4	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE B-8

PERFORMANCE OF THE DEVICES

Device: Minimonitor II, Nuclear Associates Probe: Geiger
Utilization: end of the device Centre: B

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 400		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		> 11 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		(2.5E+6)		
1	2.8E+4		N	N
7	1.4E+5		N	N
35	7.2E+5		N	N
I-123		(2.5E+6)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		> 1.9E+5	-	-
Ba-133		> 3 000	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE C-1

PERFORMANCE OF THE DEVICES

Device: Berthold LB 1200 — Probe: Geiger
Utilization: in front of the tube, 2 mg cm^{-2} mica — Centre: C

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		≥ 8 800		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		7 900		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		4.6E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(4.6E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		-	-	-
Ba-133		2 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE C-2

PERFORMANCE OF THE DEVICES

Device: Victoreen Thyac III — Probe: Scintillation
Utilization: in front of a 1" Ø x 1" crystal — Centre: C

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		7 200		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		1.0E+4		
1	2.8E+4		Y	N
7	1.4E+5		Y	Y
35	7.2E+5		Y	Y
I-123		(1 E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		-	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE C-3

PERFORMANCE OF THE DEVICES

Device: Picker Nuclear — Probe: Geiger
Utilization: in front, 2 mg cm^{-2} mica — Centre: C

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 300		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		≥ 18 500		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		1.0E+5		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	N
I-123		(1.0E+5)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		-	-	-
Ba-133		≥ 4 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE D-1

PERFORMANCE OF THE DEVICES

Device: Berthold LB-1210D — Probe: 100 cm^2 proportional counter

Utilization: in front, (5 mg cm^{-2} titanium) — Centre: D

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity (3) (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		600 and 6 000		
1	180		N,N	N
2	380		N,N	N
5	900		Y,N	N
7	1 300		Y,N	N
14	2 200		Y,N	N
21	2 900		Y,N	N
28	3 500		Y,N	N
49	4 400		Y,N	N
I-131		2 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		2.8E+3 and 2.9E+4		
1	2.8E+4		Y,Y	Y,N
7	1.4E+5		Y,Y	Y,N
35	7.2E+5		Y,Y	Y,Y
I-123		(2.7E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		25 000	-	-
Ba-133		1 700	-	-

(1) N = NO / Y = YES / - = not applicable

(2) Value shown is an average of measurements of other similar energy sources.

(3) MDA calculated on the basis of the values of the proportional chamber in contact with the phantom, 100 cm^2 probe.

TABLE D-2

PERFORMANCE OF THE DEVICES

Device: Nuclear Chicago 2650 Probe: Geiger
Utilization: in front of mica, 2mg cm^{-2} Centre: D

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 300		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		> 10 800		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		2.4E+5		
1	2.8E+4		N	N
7	1.4E+5		N	N
35	7.2E+5		Y	N
I-123		(2.4E+5)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		≥ 3.4E+4	-	-
Ba-133		> 2 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE D-3

PERFORMANCE OF THE DEVICES

Device: Nuclear Chicago 2650 Probe: Geiger
Utilization: lateral, stainless steel Centre: D

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 300		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		> 10 800		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		2.4E+5		
1	2.8E+4		N	N
7	1.4E+5		N	N
35	7.2E+5		Y	N
I-123		(2.4E+5)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		≥ 3.4E+4	-	-
Ba-133		> 2 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE D-4

PERFORMANCE OF THE DEVICES

Device: Searle Log Series — Probe: Geiger
Utilization: lateral, 30 mg cm^{-2} section — Centre: D

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 300		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		> 10 800		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		9.3E+5		
1	2.8E+4		N	N
7	1.4E+5		N	N
35	7.2E+5		N	N
I-123		(9.3E+5)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		> 34 000	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE E-1

PERFORMANCE OF THE DEVICES

Device: Victoreen Minimonitor 125 Probe: Geiger
Utilization: in front, without cap Centre: E

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		4 800		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		2 700		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		2.2E+4		
1	2.8E+4		Y	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(2.2E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		≥ 3 500	-	-
Ba-133		2 600	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE E-2

PERFORMANCE OF THE DEVICES

Device: Nuclear Chicago 2650 Probe: Geiger
Utilization: lateral, stainless steel Centre: F

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 300		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		≥ 14 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		4.4E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(4.4E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		> 3 200	-	-
Ba-133		> 2 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE E-3

PERFORMANCE OF THE DEVICES

Device: Nuclear Chicago 2650 Probe: Geiger
Utilization: in front of 2mg cm^{-2} mica Centre: E

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		4 900		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		6 900		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		3.6E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(3.6E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		> 3 200	-	-
Ba-133		> 2 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE F-1

PERFORMANCE OF THE DEVICES

Device: Berthold LB 1200 Probe: Geiger
Utilization: in front of 2mg cm^{-2} mica Centre: F

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		11 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		14 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		5.2E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(5.1E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		5.1E+4	-	-
Ba-133		> 2 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE F-2

PERFORMANCE OF THE DEVICES

Device: Victoreen 498 — Probe: Geiger
Utilization: lateral, 30mg cm^{-2} window — Centre: F

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		6 200		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		8 100		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		3.8E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(37 000)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		37 000	-	-
Ba-133		1 200	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE G-1

PERFORMANCE OF THE DEVICES

Device: Victoreen, Frisker 425 Probe: Geiger
Utilization: lateral, 30mg cm^{-2} window Centre: G

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		15 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		11 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		4.4E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(4.4E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		-	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE G-2

PERFORMANCE OF THE DEVICES

Device: Victoreen 440 — Probe: Ionization chamber
Utilization: in front, thin window — Centre: G

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		> 7 300		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		22 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		1.E+6		
1	2.8E+4		N	N
7	1.4E+5		N	N
35	7.2E+5		N	N
I-123		(1.E+6)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		-	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE H-1

PERFORMANCE OF THE DEVICES

Device: Nuclear Chicago 2652 — Probe: Geiger
Utilization: in front, mica 2mg cm^{-2} window — Centre: H

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		9 400		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		6 300		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		(6.0E+4)(2)		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		6.0E+4		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		-	-	-
Ba-133		> 2 700	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE H-2

PERFORMANCE OF THE DEVICES

Device: Picker Lab. Monitor — Probe: Geiger
Utilization: in front, 1" Ø mica — Centre: H

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		11 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		13 000		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		8.4E+4		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	N
I-123		84 000		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		-	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE J-1

PERFORMANCE OF THE DEVICES

Device: Ludlum 14 C — Probe: Geiger "Pancake"
Utilization: in front, 2mg cm^{-2} mica — Centre: J

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		5 100		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		8 400		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		-	-	
1	2.8E+4			
7	1.4E+5			
35	7.2E+5			
I-123		-	-	
1	4 800			
2	2 800			
5	160			
7	18			device no longer available for test
Co-57		-	-	
Ba-133		-	-	

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE J-2

PERFORMANCE OF THE DEVICES

Device: Ludlum 177 — Probe: Scintillation
Utilization: in front, 2" Ø x 2 mm crystal — Centre: J

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity 5 cm away from the phantom (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		2 000		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		Y	N
21	2 900		Y	N
28	3 500		Y	N
49	4 400		Y	N
I-131		1 200		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		(3 700)(2)		
1	2.8E+4		Y	N
7	1.4E+5		Y	Y
35	7.2E+5		Y	Y
I-123		(3 700)(2)		
1	4 800		Y	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		3 700	-	-
Ba-133		1 000	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.

TABLE J-3

PERFORMANCE OF THE DEVICES

Device: Eberline ESP-1 — Probe: Scintillation
Utilization: in front of 1" x 1" crystal — Centre: J

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity $\frac{(3\sqrt{B})}{(f)}$ (3) (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		240		
1	180		N	N
2	380		Y	N
5	900		Y	N
7	1 300		Y	N
14	2 200		Y	N
21	2 900		Y	Y
28	3 500		Y	Y
49	4 400		Y	Y
I-131		460		
1	140		N	N
2	260		N	N
5	500		Y	N
7	590		Y	N
14	600		Y	N
Tc-99m		(210) (2)		
1	2.8E+4		Y	Y
7	1.4E+5		Y	Y
35	7.2E+5		Y	Y
I-123		(210) (2)		
1	4 800		Y	Y
2	2 800		Y	Y
5	160		N	N
7	18		N	N
Co-57		210	-	-
Ba-133		500	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.
(3) Integration: 60 seconds. Measurement at 5 cm from the phantom.

TABLE J-4

PERFORMANCE OF THE DEVICES

Device: Eberline ESP-1 Probe: Geiger
Utilization: lateral, compensated HP-270 Centre: J

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity (3) (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		≥ 8 600		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		N	N
21	2 900		N	N
28	3 500		N	N
49	4 400		N	N
I-131		11 500		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		(6.4+E)(2)		
1	2.8E+4		N	N
7	1.4E+5		Y	N
35	7.2E+5		Y	Y
I-123		(6.4E+4)(2)		
1	4 800		N	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		6.4E+4	-	-
Ba-133		-	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.
(3) Integration: 60 seconds. Measurement at 5 cm from the phantom.

TABLE J-5

PERFORMANCE OF THE DEVICES

Device: Berthold LB 1210B Probe: 200 cm^2 proportional
Utilization: in front of (5mg cm^{-2} titanium) Centre: J

ISOTOPE / Interval (days)	Investigation Level (Bq)	Minimum Detectable Activity (3) (Bq)	Satisfactory for Atomic Radiation Workers (1)	Satisfactory for Others Workers (1)
I-125		1 500		
1	180		N	N
2	380		N	N
5	900		N	N
7	1 300		N	N
14	2 200		Y	N
21	2 900		Y	N
28	3 500		Y	N
49	4 400		Y	N
I-131		950		
1	140		N	N
2	260		N	N
5	500		N	N
7	590		N	N
14	600		N	N
Tc-99m		(4.7+E3)(2)		
1	2.8E+4		Y	N
7	1.4E+5		Y	Y
35	7.2E+5		Y	Y
I-123		(4.7E+3)(2)		
1	4 800		Y	N
2	2 800		N	N
5	160		N	N
7	18		N	N
Co-57		4.7E+3	-	-
Ba-133		790	-	-

(1) N = NO / Y = YES / - = not applicable
(2) Value shown is an average of measurements of other similar energy sources.
(3) MDA calculated on the basis of the results of the proportional chamber in contact with the neck.